

Variability of Irradiance in the Wave Boundary Layer

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LONG-TERM GOALS

Our primary goal is improve our understanding of the role of surface waves, bubble clouds, and near-surface oceanic processes on the spatial distribution of oceanic irradiance.

SCIENTIFIC OBJECTIVES

The objectives are to:

- Measure the variance in the oceanic light field.
- Measure turbulence velocity and temperature fluctuations in the water column.
- Associate the variance in the light field with surface waves and variance in the inherent optical properties and physical properties.

APPROACH

This year we modified our approach because of the desire to operate under high wind conditions. Therefore we prepared for both ship-based vertical profiling and AUV-based spatial survey programs. Instead of using the large Bluefin AUV that we have operated in the past, we contracted with Mark Moline's group at Cal Poly to operate their REMUS-100 vehicle with scattering, chlorophyll, and seven channel irradiance sensors. The smaller vehicle is easier to retrieve in higher seas. While easier to retrieve our ability to launch and retrieve the AUV was dependent on being able to launch a small boat from the Kilo Moana, which did limit the number of AUV operations during the August-September 2009 field experiment.

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The AUV-based Rockland Scientific Inc (RSI) microstructure package was modified to free fall vertically. We also built a small optical profiler that could be used to characterize optical properties away from the ship and to collect coincident IOP (a, c, bb) and radiometric (Ed Lu) properties from the ship. To achieve high-resolution irradiance measurements we integrated two Biospherical single wavelength irradiance sensors into the RSI microstructure package (hereinafter referred as vertical microstructure profiler (VMP)). This sensor has the high sampling rate that is needed to achieve small, spatial-scale irradiance measurements. The VMP was deployed in a profiling mode to determine microstructure properties. We deployed it with a small float to reduce the descent rate to get higher resolution irradiance profiles. We also attached it to a larger float to collect time series at fixed depths near the surface. The large float allowed the system to follow the swell, but did not respond to small waves so the depth variations were tens of centimeters in 2-3 m waves.

The AUV was flown along several isobars to measure the light field, IOPs and physical properties. Along each isobar it is possible to determine the power spectrum of irradiance fluctuations and provide other statistics related to the variability in the light field. These statistics can then be compared to the variability in modeled light fields. The AUV is also being used to measure the variability in physical and optical properties near FLIP and the Kilo Moana.

A vertical optical profiler (hereinafter referred as VOP) was also constructed to collect inherent and radiometric optical property measurements when the AUV was unable to operate. These measurements provide a more complete time series of optical variability when combined with the measurements of Twardowski et al. A bioluminescence sensor was also added to the profiler during night time operations.

WORK COMPLETED

Analysis of Data from Santa Barbara, 2008 Experiment: We have examined horizontal variability of irradiance and high-frequency temperature records collected from Bluefin AUV. A couple of manuscripts are in preparation and some of observations are presented in the RESULTS section.

Hawaii, 2009 Experiment: We converted the microstructure sensors to a vertical profiler and trained with the new configuration between cruises. We also trained with the group from Cal Poly on the use of the REMUS, and removed the optical sensors from the OSU Bluefin for use as an optical profiler. All of these systems were used during the field experiment in August and September of 2009. We have collected 325 VMP profiles, and 42 VOP profiles covering three phases of the day (mooring, midday, and nighttime). The number of AUV runs (e.g., Figure 3) was limited to three because its operation has been limited by our ability to launch the small boat for retrieval in the higher sea state conditions experienced during the experiment.

RESULTS

During the 2008 experiment off Santa Barbara the AUV was used in a profiling mode as well as running at fixed depths. We found a coherence between the high-frequency temperature and the light fields (Figure 1 and 2). The magnitude of the temperature signal is greater than what would be expected based on wave induced vertical movement in the water column suggesting that wave focusing may create localized heating that is detectable.

The short wave number fluctuations decreased as a function of depth (Figure 3 and 4). Near the surface fluctuations are observed down to scales of a few centimeters, which is the resolution of the sampling technique. By the time the instrumentation is at six meters depth the fluctuations on scales less than 10 centimeters has decreased by an order of magnitude. By twelve meters they have decrease three and a half orders of magnitude at the 10 cm scale and are effectively in the noise floor. Light fluctuations were still observable down to thirty meters depth. The peak at 4×10^{-2} is caused by vehicle motion as it tries to follow an isobar. The shorter peaks are likely to be associated with waves of different wavelengths.

Figure 4 shows the variability in the light field as a function of frequency off Hawaii. Again we observe the decay in the high frequency component, but at a much lower rate than off Santa Barbara. We hypothesize that the change in the decay rate is primarily due to the scattering coefficient being an order of magnitude smaller off Hawaii than off Santa Barbara. A question that we continue to try and address is why the high frequency component exists. Focusing from a single wave is not expected at frequencies above about 20 Hz and the frequency should decrease as a function of depth, however; a high frequency component does exist. We hypothesize that the high frequency component is a result of waves modifying the edge of the Snell cone. Since this involves the summation of several waves we expect that a higher frequency fluctuation can occur. When considering the decay of the high frequency component we now need to consider the path length increase associated with the edge of the Snell cone and the possibility that at increasing depth the greater surface area observed along the edge of the Snell cone allows for the high-frequency component to be averaged out.

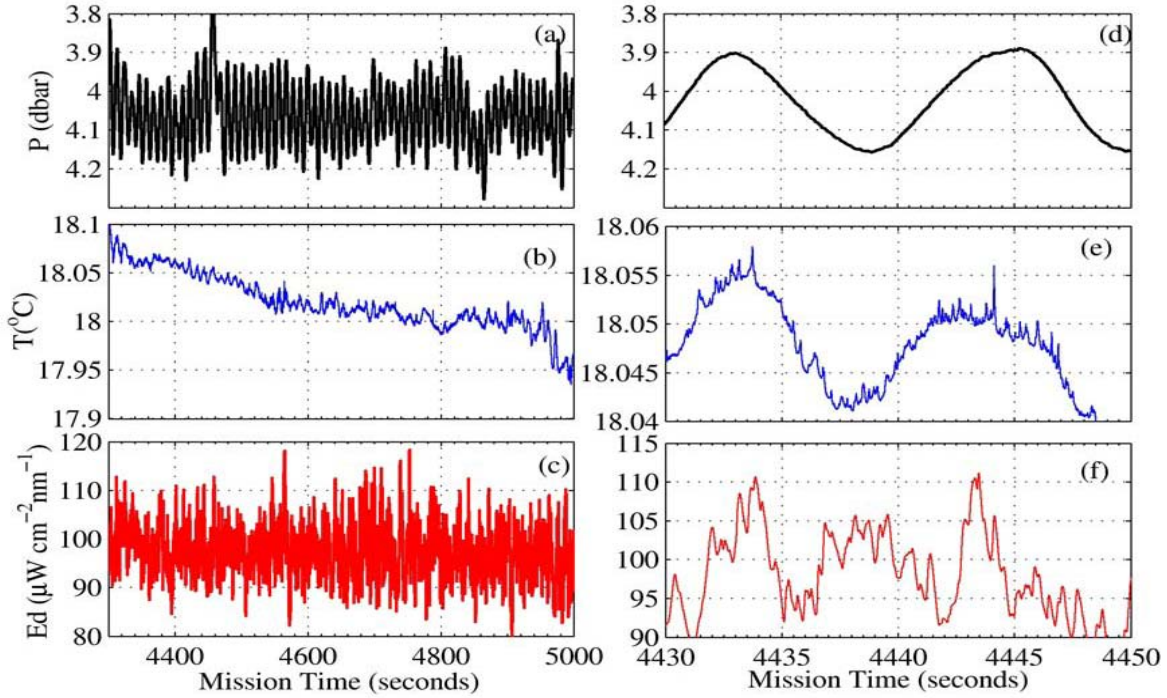


Figure 1. Time series of AUV observations at 4 m water depth. A trace of pressure P (a), Temperature T (b), and downwelling irradiance Ed at 490 nm (c). Sampling rates of P , T , Ed were 32 Hz, 512 Hz, and 512 Hz respectively. Right panels (d,e,f) show subset of P , T , and Ed illustrating small-scale variability.

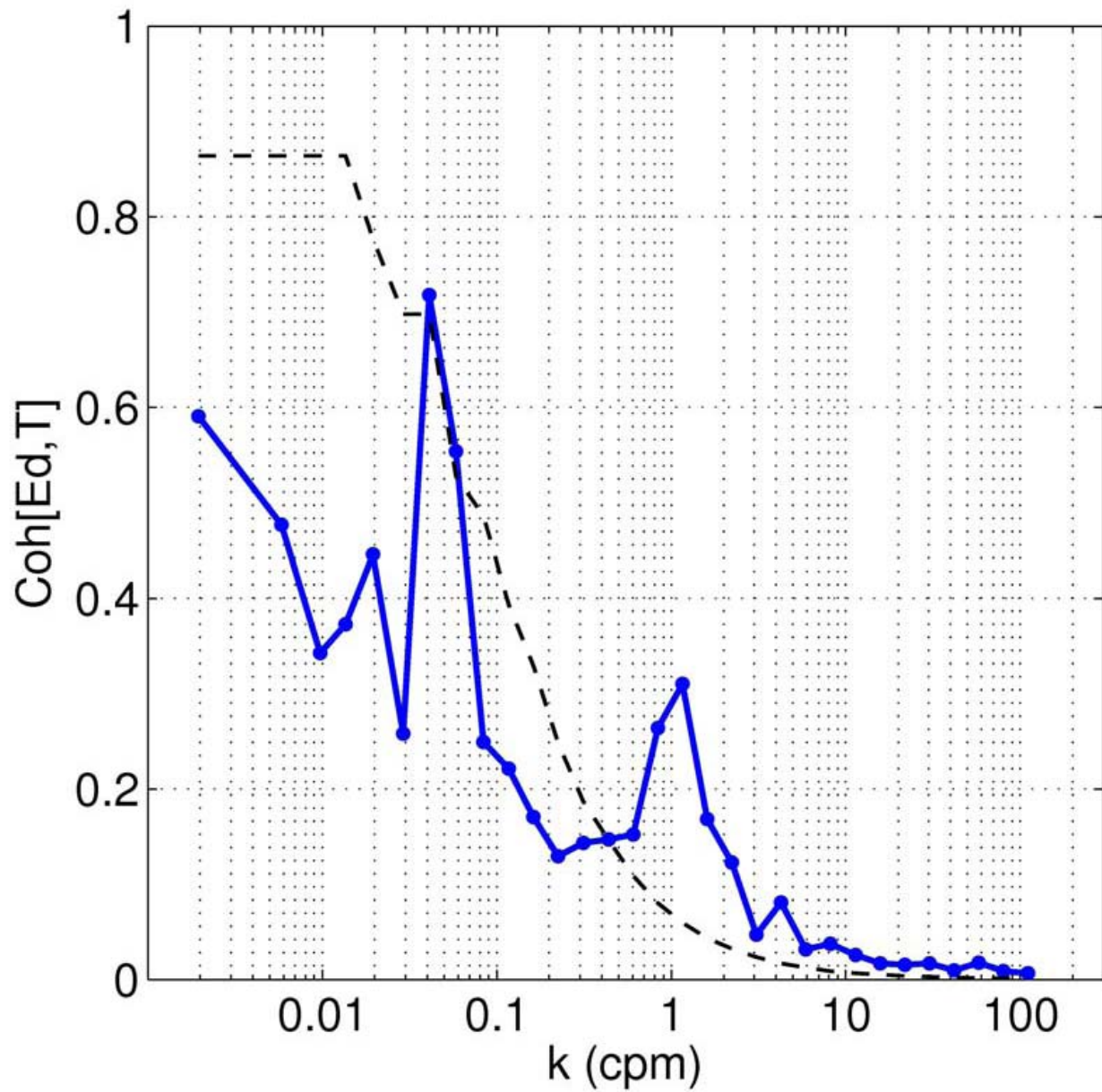


Figure 2. Coherence between T and Ed at 4 m depth averaged for the entire record. The dashed (black) line denotes the 95% confidence level for 0 true coherence. Near 1 cycle per meter there is significant coherence between the signals.

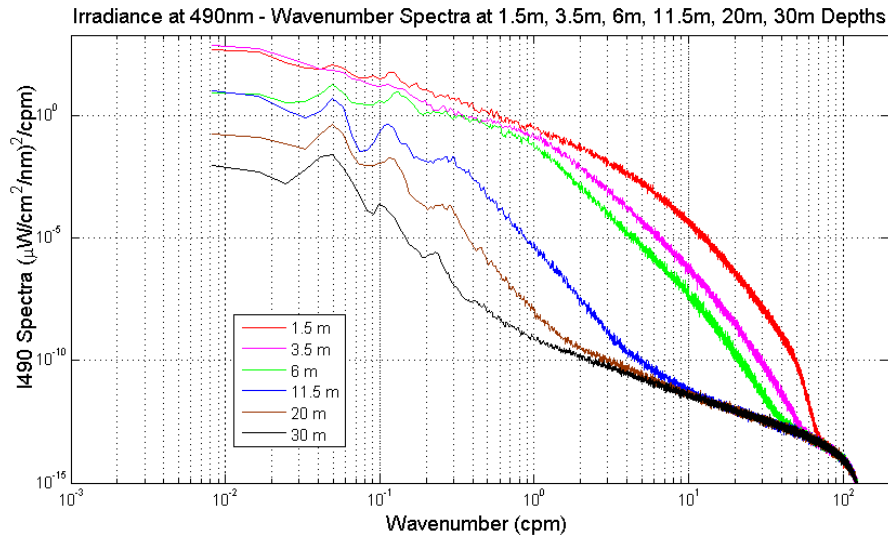


Figure 3. Shown is the wave number spectra at six depths for irradiance at 490 nm observed on Sep 20, 2008. Westerly winds were about 6 m/s and solar insolation varied from 650 to 850 W m⁻² during the observation. The fluctuations at shorter wave numbers decrease rapidly with depth.

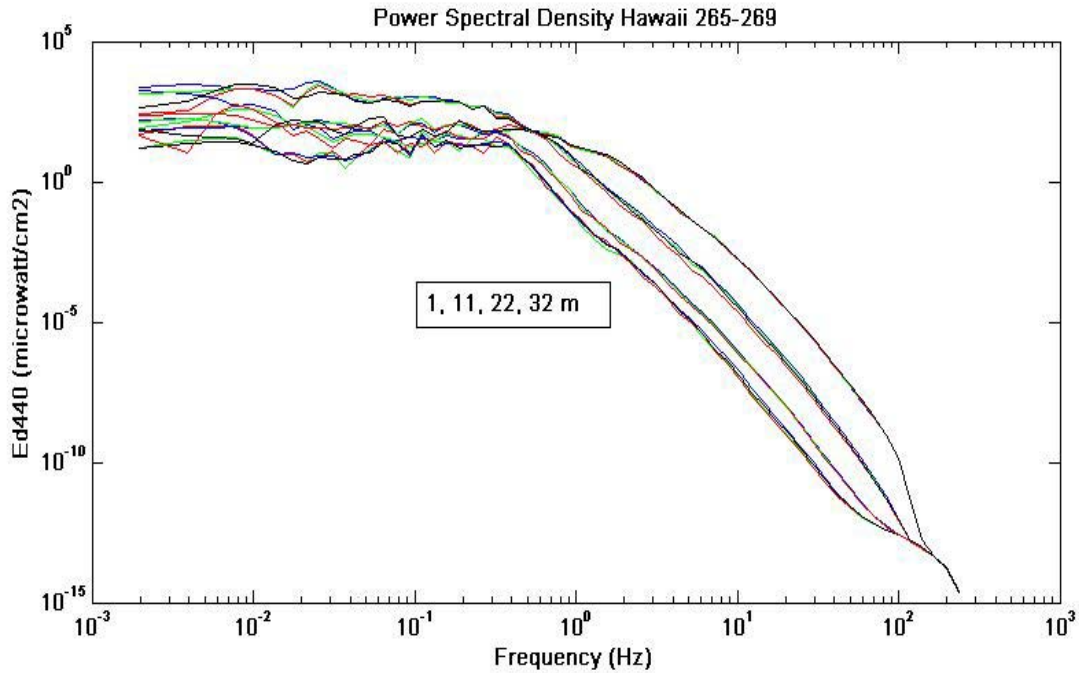


Figure 4. Shown is the power density spectra at four depths for irradiance at 490 nm observed south of Hawaii on Sep 11, 2009. At 1, 11, 22, and 32 m in order from top to bottom. Again we observe a decrease in the high-frequency light fluctuations, however; at a much greater depth than in the Santa Barbara Channel. This is primarily due to the scattering coefficient being an order of magnitude smaller off Hawaii.

IMPACT/APPLICATIONS

None

RELATED PROJECTS

Other projects participating in the RaDyO program. <http://www.opl.ucsb.edu/radyo/>